# Crewed and Space Transportation Systems Cost Model
# *CAST*

## NASA Cost Symposium
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**and**
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# OUTLINE

- **CAST - What it is**
    - **Relationship to NAFCOM**
    - **Relationship to Project Cost Estimating Capability (PCEC)**

- **Development Approach**
    - **Overall goals - Philosophical framework**
    - **What we are estimating**
        - **Work and Functional Breakdown Structures (WBS & FBS)**
    - **How we are estimating**
        - **Basis of estimate – historical database**
        - **Cost Estimating Relationship (CER) development**

- **End Product**
    - **Model and data**
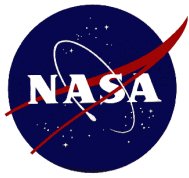    - **Depth and breadth**

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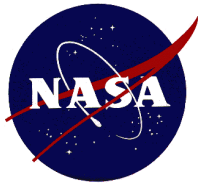
# CAST – What It Is

- **What it is**
  - New, unique cost model for use in estimating space transportation systems, including crewed systems, and earth-to-orbit and in-space transportation systems.

- **Relationship to NAFCOM**
  - CAST includes, but offers a more tailored estimating capability than NAFCOM
  - NAFCOM CER historical database is point-of-departure for many of the CAST CERs
    - CAST CERs draw on NAFCOM experience, but are not necessarily the same
    - Researching/updating/documenting NAFCOM historical database to be sure we understand it
    - As applicable, segregating out spacecraft datapoints
    - Adding additional datapoints as appropriate
    - Other changes/enhancements
  - NAFCOM 12 CERs will remain accessible as-is through PCEC

- **Relationship to Project Cost Estimating Capability (PCEC)**
  - CAST will be part of/accessible through PCEC
  - Model and data/documentation (through ONCE and REDSTAR)

- **Overall goals - Philosophical framework**

    - **Definition of a model:  Mathematical relationships based on known historical data for use in estimating the cost of future systems**

    - **Focus:  The data and arithmetic; Not the "bits and bytes"**
        - We are feeding math and data to PCEC developers for incorporation in the overall PCEC

    - **Emphasis: Basis of Estimate = Traceability and transparency of estimate to database**
        - Development and documentation of the database and analytical processes behind the CERs incorporated in the model
        - Provides flexibility to use CAST data/model as point-of-departure for tailored/customized estimates
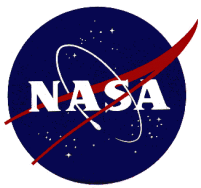
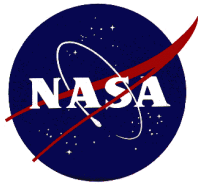# What We Are Estimating – WBS/FBS

- **What do we want to model? - Primary Assumptions/Considerations**
  - There will be a set of CERs or equivalent estimating capability available to PCEC users for each WBS line item
  - The WBS/CERs should be set up to utilize/reflect as much historical source data as possible
  - The WBS/CERs should be set up to provide users with as much useful information as possible to cover a wide range of potential uses
  - Results in need to consider multiple dimensions

- **Breakdown Structure Dimensions:**

1. **End Items (Products & Services) = WBS**
   - Point of Departure = NAFCOM (Launch Vehicle and Crew Vehicle Templates), MIL HDBK 881, Others
     - Will feed NPR 1720 (1.8) and CADRE; but estimates will be done at lower levels
     - Initially hardware only, but add launch and flight ops (and NREC facilities) to provide full LCC estimating capability

2. **Time = Non Recurring and Recurring CERs for each WBS element**

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- **Breakdown Structure Dimensions (continued):**

3. **Functions (Engineering, Touch, Mfg Support, QA, etc.) = Functional Breakdown Structure (FBS)**
   - A lot of the historical data is in this format, not by end item
   - Many (most?) cost reduction/affordability approaches relate most directly to functions, not end items
     - E.g. Touch labor vs. automated welding; SR&QA vs. reduction in Gov't Mandated Inspection Points (GMIPS); Facility O&M vs. shared facilities
   - Separate from, but equal to WBS CER results: ∑ WBS elements = ∑ FBS elements
   - CAST includes estimating relationships between WBS and FBS elements – ratio analysis

4. **Elements of Cost = Labor hours, Labor $'s, Overhead $'s, ODC's, Materials, Subcontracts**
   - Included (explicitly or implicitly) in WBS and FBS results
   - Primary inputs on (for instance ) 533 data

- **Wraps**
  - Review/define terms
    - Contractor, Non-Prime Support, Civil Service
    - Program Management & Support, SE&I, S&MA, Vehicle Integration, etc.
  - Cost-to-cost non-linear CER's (not just a %)
    - Based on historical data: R&PM, Cx, SLS, etc.
    - Non-Recurring vs. Recurring; Program Approach (e.g. Cx vs. SLS vs. Shuttle)
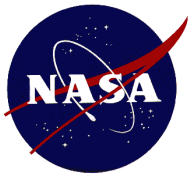
# What We Are Estimating – WBS/FBS

**Engineering Cost Office**

- Current CAST WBS

| 1 | 2 | 3 |
|---|---|---|
| **SYSTEM** | | |
| | **Program Segment** | |
| | Program Mgt & Support | |
| | Systems Engr & Integ | |
| | Safety & Mission Assur | |
| | **Vehicle Segment** | |
| | Integration, Ass'y, Checkout | |
| | Structures | |
| | | Wing |
| | | Tail |
| | | Fuselage/Body |
| | | Thrust Structure |
| | | Adapters |
| | | Holddown Structures |
| | | Secondary/Support Structs |
| | Tanks | |
| | | Fuel |
| | | Oxidizer |
| | | Intertank |
| | | Thermal Protect |
| | Mechanisms | |
| | | Flight Controls |
| | | Separation |
| | | Recovery |
| | | Umbilicals |
| | Main Propulsion Systems | |
| | | Feed |
| | | Fill & Drain |
| | | Purge & Vent |
| | | Pressurization |
| | Thermal Protection | |
| | | Passive |
| | | Active |

| 1 | 2 | 3 |
|---|---|---|
| **SYSTEM** | | |
| | **Vehicle Segment (continued)** | |
| | Propulsion | |
| | | Liquid Engines |
| | | Solid Motors |
| | | Reaction Control Sys |
| | | Orbit Maneuvering |
| | Avionics & Power | |
| | | Guidance, Nav, & Control |
| | | Communication & Tracking |
| | | Data Processing |
| | | Instrumentation |
| | | Telemetry |
| | | Thermal Control |
| | | Elec Power Generation |
| | | Elec Pwr Distribution & Control |
| | | Flight Termination System |
| | Shroud/Fairing | |
| | | Structures |
| | | Payload Accomodations |
| | | Utilties |
| | | Separation |
| | Crew Systems | |
| | | Environ Ctl & Life Support |
| | | Crew Accomodations |
| | | Displays & Controls |
| | **Software Segment** | |
| | Flight Software | |
| | Ground Software | |
| | **Test Segment** | |
| | Ground Test Operations | |
| | Special Test Equipment | |
| | Flight Test Operations | |

| 1 | 2 | 3 |
|---|---|---|
| **SYSTEM** | | |
| | **Ground Segment** | |
| | Production Faciilties | |
| | | Facility |
| | | Tooling |
| | Launch Facilities | |
| | | Pad |
| | | Vertical Processing |
| | | Horizontal Processing |
| | | Launch Control |
| | | Payload Processing |
| | | Mobile Launch Platform |
| | | Landing |
| | | Infrastructure |
| | Test Facilities | |
| | | Integrated Vehicle |
| | | Propulsion |
| | | Structures |
| | **Operations Segment** | |
| | Launch Operations | |
| | Flight Operations | |

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# What We Are Estimating – WBS/FBS

- FBS Examples:  Program & Propulsion Segments
- Works with WBS as two-dimensional matrix
  - Not every matrix "box" is relevant/has data
  - Nature of input/source data dictates which direction calculation goes

**FBS Elements**

| 1   2   3 LAUNCH SYSTEM | LABOR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Program Mgt & Support** | | | | | **Engineering** | | | | |
| | | | | | | | | **Design & Analy** | | **Special Studies** |
| | **PM&S** | **Bus Ops** | **Logistics** | **Supt Svcs** | **ODC** | **Sys Integ** | **Sys Analy** | **Analy** | **Sustain** | **Studies** |
| **Program Segment** | | | | | | | | | | |
| Program Mgt & Support | X | X | X | X | X | | | | | |
| Systems Engr & Integ | | | | | | X | X | NREC | REC | X |
| Safety & Mission Assur | | | | | | | | | | |
| **Vehicle Segment** | | | | | | | | | | |
| Propulsion | | | | | | | | | | |
| Liquid Engines | X | X | X | X | X | X | X | NREC | REC | X |
| Solid | X | X | X | X | X | X | X | NREC | REC | X |
| Rea | | | | | | | | | | |
| Orb | | | | | | | | | | |

*Some overlap with WBS line items and elements of cost*

| 1   2   3 LAUNCH SYSTEM | MATERIAL & SUBCONTRACT | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Manufacturing** | | | | **Flight Hardware** | | | **Support Hardware** | | |
| | | | | **Facility** | **Flight** | **Flight** | **Flight** | **Support** | **Support** | **Support** |
| | **Touch** | **Mfg Supt** | **SR&QA** | **O&M** | **Hdw 1** | **Hdw 2** | **Hdw N** | **Hdw 1** | **Hdw 2** | **Hdw N** |
| **Program Segment** | | | | | | | | | | |
| Program Mgt & Support | | | | | | | | | | |
| Systems Engr & Integ | | | | | | | | | | |
| Safety & Mission Assur | | | | | | | | | | |
| **Vehicle Segment** | | | | | | | | | | |
| Propulsion | | | | | | | | | | |
| Liquid Engines | X | X | X | X | Pumps | Nozzle | Controller | | | |
| Solid Motors | X | X | X | X | Case | Propellant | Nozzle | | | |
| Reaction Control Sys | | | | | | | | | | |
| Orbit Maneuvering | | | | | | | | | | |

*FBS elements can vary by WBS line item*
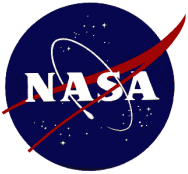
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# What We Are Estimating – WBS/FBS

- FBS CER Application Example
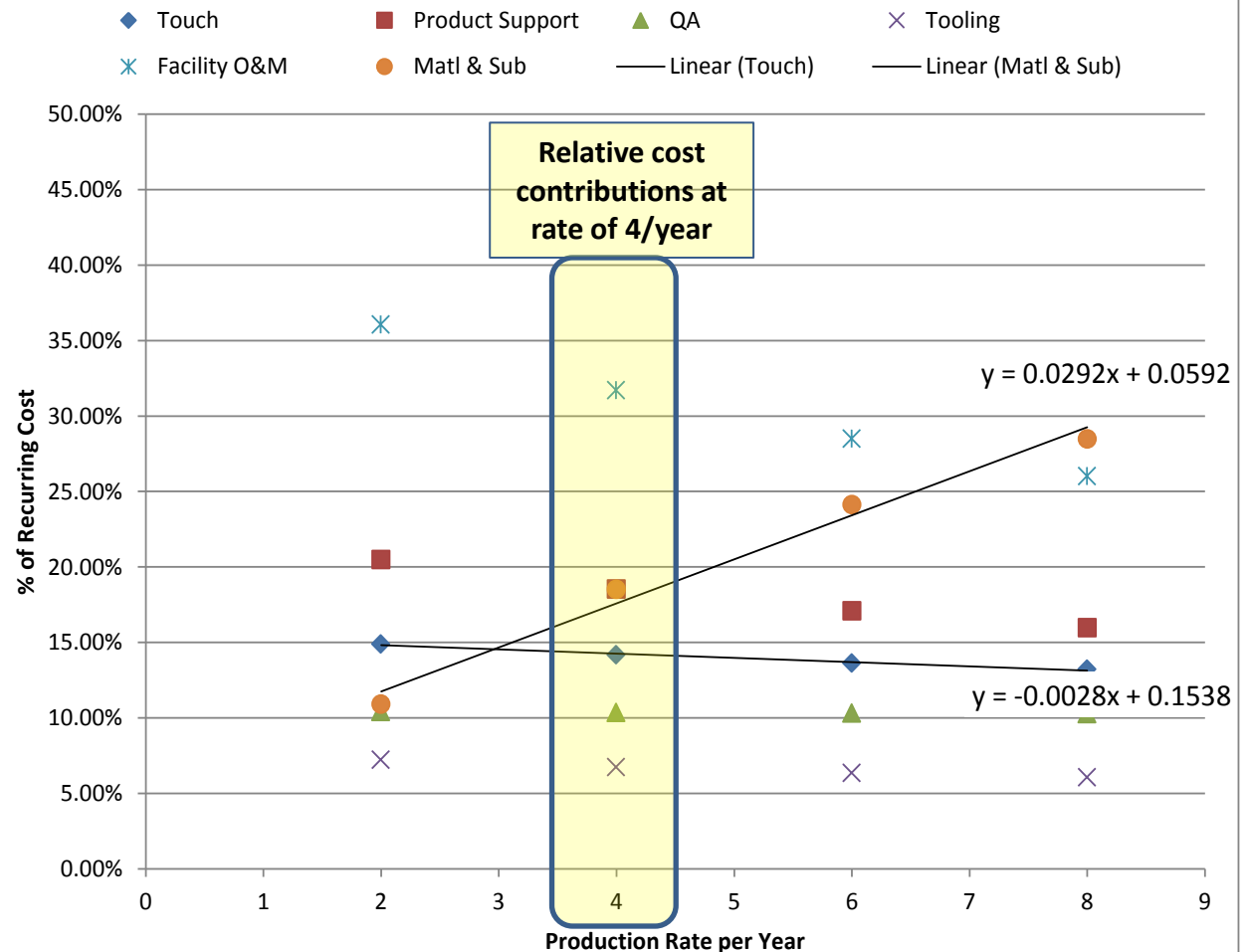
**Question:**
- **At production rate of 4 per year, what is savings if introduce automated welding equipment for propellant tank manufacturing?**
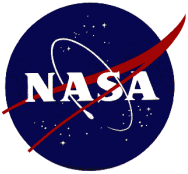
**Assume**
- **WBS Tank CER output = $10M/tank**
- **Estimated savings = 60% reduction in touch labor**

**Application**
- **Touch Labor % of Total $ = -.0028 x (rate) + .1538**
- **Touch Labor % @ 4/year = -.0028 (4) + .1538 = 14.3%**
- **14.3% x ($10M x 4) = $5.7M touch labor cost per year**
- **$5.7M x 60% = $3.4M/year savings**
- **$3.4M / $.150M/MYE = 22 EP reduction in touch labor headcount**



Legend: Touch, Product Support, QA, Tooling, Facility O&M, Matl & Sub, Linear (Touch), Linear (Matl & Sub)

Relative cost contributions at rate of 4/year

$y = 0.0292x + 0.0592$

$y = -0.0028x + 0.1538$

Y-axis: % of Recurring Cost

X-axis: Production Rate per Year

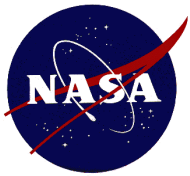KT Engineering

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# How We Are Estimating

- **Basis of estimate – historical database**
    - Evaluate the existing historical database :  relevance, validity, content, assumptions
        - E.g. Centaur G' (i.e. Shuttle Centaur) – 80's, derivative and incomplete, CISS included?, allocations?
    - Add new historical datapoints
        - Pretty sparse, mostly mods, many not completed:
            - Shuttle upgrades:  Super Lightweight ET, ASRM, MEDS (glass cockpit)
            - New programs:  ARES, Orion, J2X
            - Limited knowledge:  RS68, EELV
            - Publicly available:  supplemental (?), anecdotal vs. verifiable

- **Cost Estimating Relationship (CER) development**
    - Scarcity and age/applicability of data relative to utilization methods in CER development
    - The choice, measurement, and quantification of qualitative and/or binary independent variables
        - Dummy variables vs. "complexity" factors
            - Manned/unmanned, upper stage/booster, expendable/reusable, etc.
            - Program Approach ("Platform"), Funding Certainty, Insight/Oversight (Wraps)
            - Relative to a baseline system vs. "pure" judgment - documentation
    - Sanity checks
        - Best-fit regression results must make sense
        - A•    E.g. negative slope for New Design variable
    dd fixed/variable cost estimating capability: learning and rate curves

# How We Are Estimating

- **CER/Database Issues**
  - Scarcity and age/applicability of data relative to utilization methods in CER development
  - Example: Structures & Mechanisms

- **54 datapoints**
- **15 subsystem/component CERs**
- **5 one-point "CERs"**

- **11 (10) Vehicle Systems**
- **Latest "initial launch year" = 1986**

| | Subsystem | # Points |
|---|---|---|
| 1 | Mech.- Actuators | 1 |
| 2 | Mech. -Separation | 2 |
| 3 | Leading Edge | 1 |
| 4 | Interface Hardware | 1 |
| 5 | General | 17 |
| 6 | Mech. - Payload Bay Doors | 1 |
| 7 | Wing | 4 |
| 8 | Skirt | 4 |
| 9 | Base Heat Shield | 2 |
| 10 | Mech. - Hydraulics | 1 |
| 11 | Tank | 10 |
| 12 | Intertank | 2 |
| 13 | Thrust Structure | 4 |
| 14 | Re-Entry Heat Shield | 2 |
| 15 | Interstage | 2 |

| | Vehicle | Initial Launch Year |
|---|---|---|
| 1 | Apollo CSM | 1968 |
| 2 | Apollo LM | 1968 |
| 3 | Centaur-D | 1966 |
| 4 | Centaur-G' | *1986* |
| 5 | External Tank | 1981 |
| 6 | Gemini | 1965 |
| 7 | Shuttle Orbiter | 1981 |
| 8 | S-IC | 1968 |
| 9 | S-II | 1968 |
| 10 | S-IVB | 1968 |
| 11 | Spacelab | 1983 |
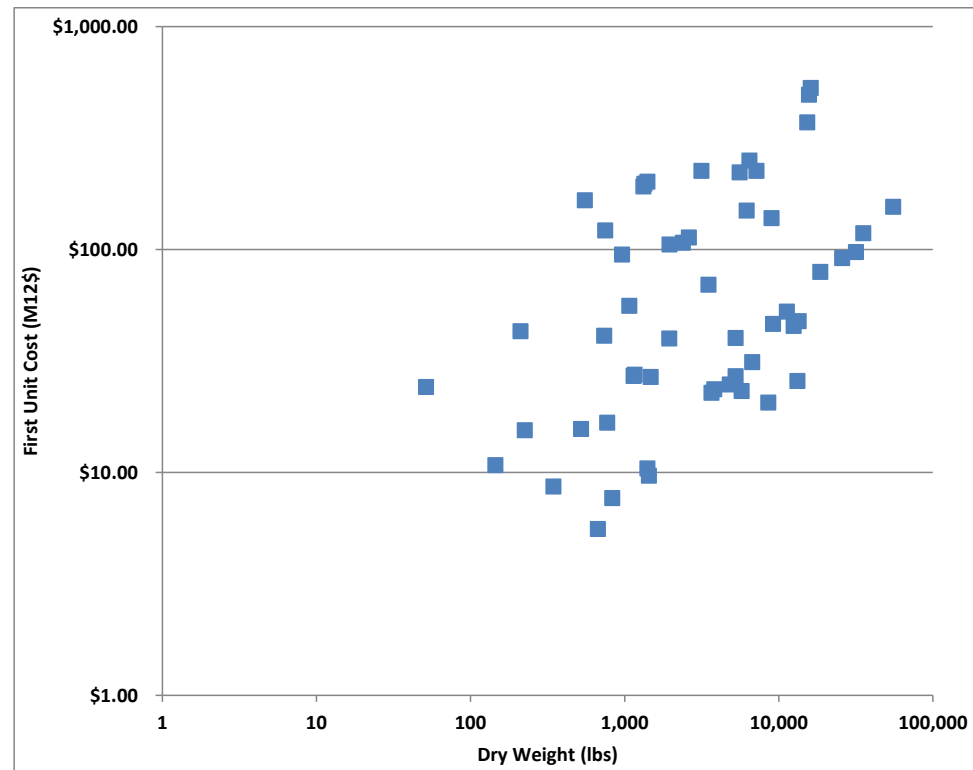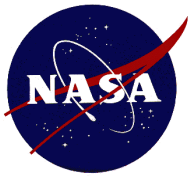
# CAST: End Product

- **Model and data: Traceability and transparency**
  - CAST will provide the end item estimating capability currently available in NAFCOM
  - CAST will add:
    - Functional estimates
    - Fixed/variable production & operations estimates
    - Other expanded capabilities
  - Updated/expanded documentation of CER analyses and historical database

- **Estimating capability:  Depth and breadth**
  - Both WBS and FBS dimensions
  - Time dimension - Full life cycle cost estimating capability:  "sand charts"
    - Spread vs. non-spread cost
    - Cost as function of flight/production rates over time
    - (Eventually) Nonrecurring facilities, mission and launch ops

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